

**Information to Support the  
Human Performance Modeling of a  
B757 Flight Crew during Approach and Landing**

**SVS Addendum**

**Prepared for:**  
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# 1 Introduction

The NASA Aviation System Program (AvSP) was created to perform research and develop technology to reduce the rate of fatal aircraft accidents in the US. Under AvSP, the System-Wide Accident Prevention project uses current knowledge about human cognition to develop mitigation strategies to address current trends in aviation accident and incident profiles. System-Wide Accident Prevention is comprised of four elements, one being Human Performance Modeling (HPM). The objective of the HPM element is to develop predictive capabilities to identify likely performance improvements and/or error vulnerabilities in human/system operation. For FY02, this element is investigating the application of HPM to predict the human performance of flight crews utilizing the Synthetic Vision System (SVS) in the cockpit. SVS depicts a clear, 3-dimensional, out-the-cockpit view of terrain, obstacles, runways, etc. to the pilot, regardless of the actual visibility or weather conditions.

The first step in the FY02 SVS modeling effort is to create a baseline human performance model of the flight crew *without* SVS. In other words, the baseline model represents today's flight deck equipment and operations. NASA decided that the flight deck for this HPM effort would be the Boeing 757. This decision was driven by the fact that SVS flight tests using a NASA-owned B757 have been conducted. The data collected from the flight tests may be used for comparison with the HPM predictions. The NASA HPM element directed the FY02 effort to focus on the approach and landing phases of flight. Indeed, improved pilot situational awareness of terrain and obstacles during approach and landing is expected to be one of the biggest benefits of SVS.

Micro Analysis and Design delivered the initial report, "Information to Support the Human Performance Modeling of a B757 Flight Crew during Approach and Landing", (Leiden et al, 2002), in March. The report contains the information for the baseline model of the flight crew *without* SVS. This document is an addendum that provides the background information and task analysis to support the modeling of the approach and landing *with* SVS.

## 2 Objective

The objective of this research was to provide the FY02 HPM teams with the necessary information to model the flight crew of a B757 during the approach and landing phases of flight. The first report documented the background information and task analysis of the current B757 approach and landing process as it is currently performed by commercial pilots. This document is an addendum that will provide additional information and task analysis data for pilots using SVS for approach and landing. It is assumed that our audience has read the first document and has a basic understanding of the approach and landing sequence as it applies to a B757 aircraft as well as a basic understanding of the instrument landing system. We have attempted not to reproduce materials from the first document. However, any background information required during the discussion of SVS that is not found in the first document is provided here.

### 3 Technical Approach

There are a number of unavoidable limitations to the type and availability of information pertaining to SVS. Unlike the first report that covered the current operations of the 757 where a huge amount of information and resources were available, the information for this report is limited because SVS is a developing system. While the basic concept hasn't changed much in the last two or three years the functional and mechanical make-up of the system has evolved with research and testing. In addition, a number of different organizations are involved in the development process, some of which intend to market SVS-like systems (Norman, 2001). As such, the system concepts vary somewhat across the different organizations. In addition, SVS has very few flight test hours with very few pilots. This limitation has made it difficult to gather reliable information on how pilots use (or will use) SVS and how that use differs from that of current operations.

Despite these problems, we were able to obtain several documents describing the current SVS configuration issues and plans. The primary source of these documents has been the SVS section of NASA's Aviation Safety Program web site ([avsp.larc.nasa.gov/images\\_svs.html](http://avsp.larc.nasa.gov/images_svs.html)). This site provides downloads for a number of documents and videos related to the SVS program. These include concepts of operation, configuration concepts and reviews, flight test plans and reports, and experimental results.

The most recent flight test of SVS was conducted in the Fall of 2001 at the Eagle/Vail airport in Colorado (FAA designation EGE). EGE was chosen due to the terrain challenges and lack of precision support equipment. NASA's B757 test aircraft was fitted with a concept SVS for these tests. Personnel from the NASA Langley office provided a number of documents and information from this flight test that was not available on the web site as of the date of this document. In addition, we were able to interview one of the pilots who used SVS during the EGE flight tests.

Addition documentation from the EGE test flight will be made available by the NASA Langley office through the SVS web site as it becomes available. This report will discuss some of the information that may become available that we believe would be of interest to the modeling teams. In addition, NASA Ames is conducting a simulation experiment comparing pilot performance with and without SVS. The results of this work will be made available to the modeling teams, but was not available to include in this document. We have included a section describing this experiment and the type of information that will be available.

The information collected from the available literature and the SMEs has been integrated and decomposed into the following sections:

- Background information about SVS
- Simulator Experiments and Flight Tests.
- Pilot use of SVS including task and cue information.

## 4 Background Information

This section will provide background information on SVS including a general overview of the system and how it works as well as detailed descriptions relevant to approach and landing and a discussion of the concept of operations for the system. It is important to realize that as a developing product the details of system implementation will change as experiments and tests are completed and new system components are integrated. As such, the system components and detailed descriptions provided here represent only a snapshot in time of system configuration and implementation. While modeling efforts will necessarily have to focus on one system configuration, it is incumbent on the teams to evaluate updated information to determine model saliency. In addition, while the SVS summary provided here gives a broad overview, the detailed descriptions will focus on aspects of the system related to approach and landing. For those interested in details of other aspects of the system, further information is available on the NASA Aviation Safety Program web site.

### 4.1 Synthetic Vision System (SVS) Overview

SVS is a cockpit system that allows pilots to view a computer-generated image of what is ahead of the aircraft independent of weather or time of day (NASA Langley, 2001). The SVS image includes terrain and airport details and may include other aircraft, weather and wake turbulence information. In addition flight data information is overlaid on the terrain background along with a tunnel navigation aid that presents a highway-in-the-sky for the pilot to follow. Figure 1 shows an early SVS terrain display with the flight data overlay.



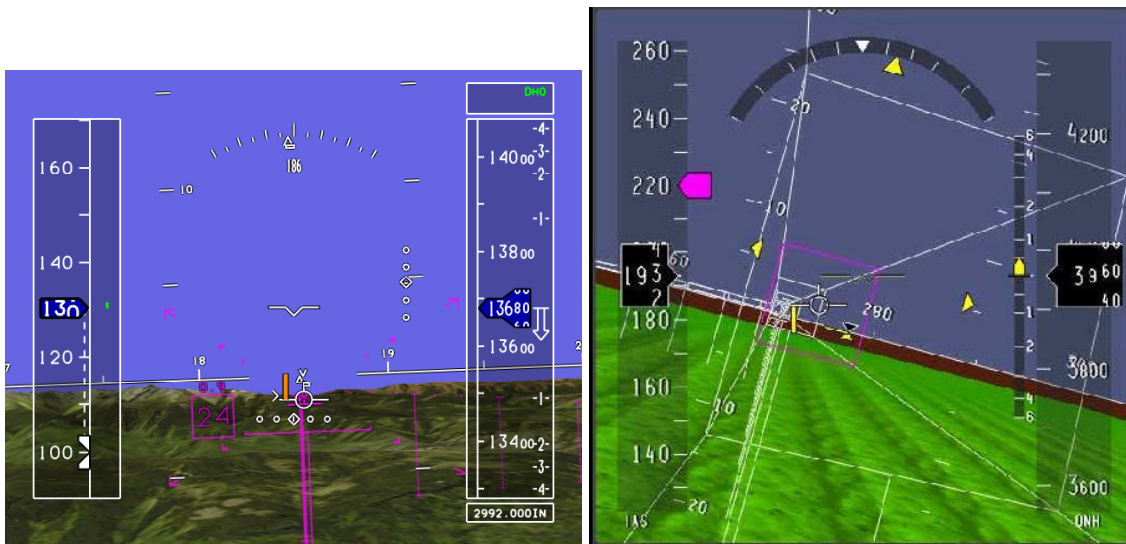
**Figure 1 - SVS Terrain and Airport display with instrument overlay.**

The system will use global positioning system (GPS) signals to orient the presented image with the actual location of the aircraft relative to the terrain. This allows the terrain image to dynamically represent what the pilots would see out the window on a clear day as the flight progresses.

SVS is being designed as a multi-component system. According to the recently updated candidate concepts document (Norman, 2002), the current system components come in three categories; Sensors/Database, Computation, and Display. The components listed in the Sensors/Database category include Forward Looking Infrared (FLIR), Millimeter Wave Radar (MMWR), Weather Radar, Aircraft Navigation Data, Aircraft State Data and Hazard Information Systems. The components listed in the computational category include an SVS dedicated computer that will perform the tasks of Perspective Transformation, Data Fusion, Image Object Detection, Symbology Generation, Integrity Monitoring and Interface / Communication along with other aircraft systems such as the Flight Management System, Ground Proximity Warning System, and the Central Alert and Warning System. The components list in the Display category include the Primary Flight Display, Navigation Display, Vertical Situation Display, Head-Up Display, Electronic Moving Map and other auxiliary displays.

Although interesting, a more detailed description of all the potential components of SVS is not provided in this document. It is likely that the exact combination and configuration of many of the systems will change as further research and development is done. For the purposes of the modeling effort, it should be safe to assume that the system will include combinations of components, interactions and integrity checks sufficient to provide the flight crew with a reliable system. For more details on the SVS system components see the concept of operations (Williams et al, 2001) and concept description (Norman, 2002) documents.

The following are descriptions of the primary flight display concepts of the system. The purpose here is simply to present some of the differences in the design concepts. It should be understood that the concept designs are in-progress and will change as the project continues. Figure 2 shows two different primary flight display concepts from NASA and Rockwell Collins.



**Figure 2 - NASA SVS Concept (left) and Rockwell Collins Concept (right)**

### Terrain Map

The terrain map is the computer-generated image of the terrain from the pilot's viewpoint. The expectation has been that the use of the image will be highly intuitive as it replicates what the pilot would see out the window in daytime VMC. The image is generated from a terrain database and can be implemented in a number of different ways. In one of the NASA concepts, a technique called photo-realism is used to combine the terrain database information with high-resolution photos of the area. The Rockwell Collins concept uses a graphical texturing technique over terrain altitude information to create the image.

### Primary Flight Display Information

The flight display information includes much the same information as presented on the current B757 ADI including speed and altitude on vertically oriented bars on either side of the display and heading on a compass arc at the top of the display. Approach guidance information for horizontal and vertical path orientation and artificial horizon are also included. These instrument displays do not differ much between the two SVS concepts.

### Velocity Vector

The velocity vector, also called the flight path symbol, represents the flight path actually followed by the aircraft. Control inputs by the pilot cause the symbol to move providing instant feedback. In essence, the pilot uses the aircraft controls to position the symbol in the display in the desired direction of travel. While the velocity vector is not available on current B757 instruments it is available on other aircraft. A velocity vector is implemented in both concepts discussed here.

### Tunnel Navigation

The tunnel navigation or highway-in-the-sky is a flight path presentation concept. The system uses graphics on the terrain display to show the desired flight path as it extends out in front of the aircraft. The NASA tunnel graphic uses brackets to indicate the corners of the tunnel and a 'T' shape or goal post to indicate the bottom of the tunnel and distance to the ground. It also uses a graphic of an aircraft, sometimes called a ghost or *follow-me* aircraft that travels ahead of the aircraft along the path of the tunnel. The Rockwell Collins tunnel graphic uses connected squares that reduce in size to present the image that the tunnel extends ahead of the aircraft. A magenta colored box moves ahead of the aircraft along the path of the tunnel.

The actual display configuration concept depends on the retrofit ability of different aircraft cockpit configurations. Older aircraft that do not already include electronic cockpit displays may require a HUD-like system mounted above the instrument display panel. Glass cockpit aircraft may be able to use their current electronic screens for the SVS terrain and flight data displays. Many of the current simulation and flight tests are designed to determine the configuration and effectiveness of a variety of retrofit options.

## **4.2 Concept of Operations**

The designers of SVS have defined a concept of operations for the system that ranges across all phases of flight and focuses on safety and improved operating efficiency

(Williams et al, 2001). This section will present a basic overview of this concept followed by a more detailed concept description of the approach phase of flight.

The intent of the concept of operations is that the system will allow aircraft to operate in low visibility conditions with the same, or greater, level of safety and by similar rules as those used during conditions of high visibility. VFR assumes that a pilot can see other nearby aircraft. As such, the flight rules allow for reduced aircraft spacing and aircraft following and parallel approach patterns. This translates to a greater operational tempo as more aircraft can occupy a given airspace. In addition, the pilot can see the airport and any obstacles to the approach path at a much greater distance. In low visibility conditions the flight rules change to reduce the risk created by the loss of visual cues. IFR requires increased aircraft spacing and specific airport-aircraft instrument combinations to continue operations. As such the operational tempo is reduced. For more details on the ILS approach process, see Leiden et al, 2001, section 4.1.

The SVS concept of operations specifies the support of the operational tempo and safety levels of VFR conditions during IFR conditions down to Cat IIIB visual minimums while using non-ILS equipped airports and runways. In other words, airports that are not currently equipped with ILS systems should be able to use VFR aircraft spacing rules in IMC down to very low visibility levels if the aircraft are equipped with SVS.

In addition, the SVS concept includes path control and hazard avoidance. Path control relates to the ability of the pilot to identify and follow a cleared or desired flight path. The tunnel navigation concept of current SVS designs is focused on improving path control beyond current instrument support systems. The focus on hazard avoidance is one of the critical safety elements of SVS. The system should increase the ability of pilots to detect, identify, prioritize and avoid hazards that include traffic, terrain, structures, wildlife and weather.

In addition to the potential change to aircraft spacing rules, SVS notionally supports several other approach operations (Williams et al, 2001). At airports where approach system components are inoperative or unavailable, SVS could be used to support approaches using VFR criteria. An example might be the ability to use lower visibility minima when approach lighting is inoperative or to continue operations when runway edge lighting is inoperative. SVS could also be used to augment current instrument systems either as an independent check of accuracy or as an addition that supports the use of lower visibility minima than would otherwise be allowed based on the ILS system at a given facility. Approach path control could be enhanced by the tunnel navigation component of SVS. This could include circling approaches that require runway alignment following difficult arcing and descending maneuvers and published visual approaches that follow terrain features could be performed in IMC. SVS would also support the avoidance of CFIT on approach. It is presumed that given a view of terrain hazards similar to daytime VFR, a pilot will be able to proactively avoid flying into a hillside, mountain or other terrain. Pilots will also be able to use SVS-based cues to prevent initiating an early or late descent that may result in landing short or long of the runway.



## 5 Simulator Experiments and Flight Tests

There have been a number of simulator experiments and flight tests throughout the SVS project. The original tests were focused on proof-of-concept evaluations or on phases of flight other than approach. As such the information gathered may be of limited use to the current modeling effort. Many documents related to these early test may be found on NASAs Aviation Safety Program web site, [avsp.larc.nasa.gov/images\\_svs.html](http://avsp.larc.nasa.gov/images_svs.html). The most recent flight test focused on the approach phase of flight and collected path error and SA data that may be useful to the modeling effort. In addition, an up-coming simulation-based experiment at NASA Ames will be done specifically to provide data to the human performance modeling teams. The rest of this section summarizes these two efforts.

### 5.1 Eagle/Vail Flight Test

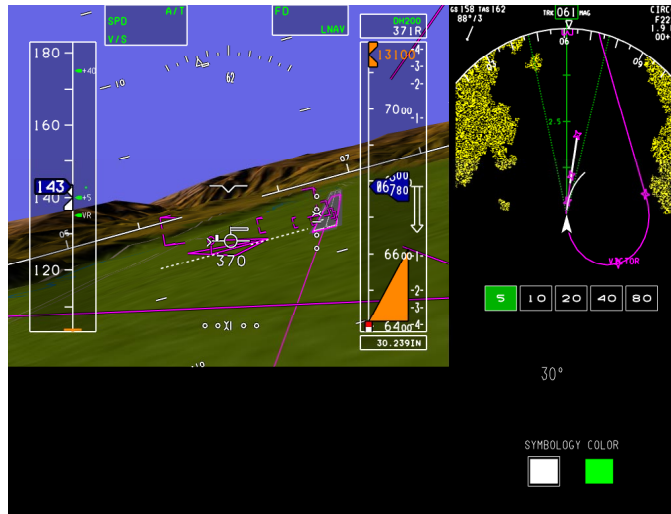
The SVS flight test at the Eagle/Vail (EGE) airport was conducted in August and September of 2001. EGE was chosen due to its terrain challenged environment in the mountains of Colorado and the high amount of air traffic it sees during ski season. The SVS concept uniquely supports airports such as EGE. An initial report documenting the results of the flight test is available (Bailey et al, 2002).

An SVS system was mounted in the cockpit of the NASA Langley B757 ARIES research aircraft. A display screen was placed over the left seat flight displays (Figure 3) to be used by the evaluation pilots in a heads-down configuration. A HUD concept was also installed to represent the retrofit system for older aircraft.



**Figure 3 - SVS in ARIES**

The heads-down display was used to render both the heads-down SVS instrument concept and the baseline non-SVS flight instruments. However, the non-SVS displays did not exactly duplicate the standard ADI of the B757. Rather, it was similar to the instrument overlay of the SVS concept. This was done to keep the instrument display as a constant throughout the test. Figure 4 shows one of the SVS concepts as displayed for the flight test. It includes the primary flight display on the left and the navigation display on the right.



**Figure 4 - Flight Test SVS Concept Display**

Evaluation pilots flew a number of approaches with their forward view blocked to simulate IFR conditions. A test safety pilot occupied the right seat. Following each approach sequence, the safety pilot assumed control and executed a go-around. The experiment included comparisons of display sizes, heads-down versus HUD concepts and tunnel navigation against the non-SVS baseline condition. Horizontal and vertical path errors were recorded during the flights and post flight questionnaires assessed subjective measures of terrain awareness and SA. Pilots reported significantly improved terrain awareness using the heads-down SVS concept over the baseline conditions and somewhat better terrain awareness with the HUD SVS concept over the baseline condition. To date, the SA data has not been published.

There are some limitations to this test flight that need to be understood by the modeling teams. The main issue is the procedures that controlled the environment in which the test pilot interacted with the system. The purpose of the test was to evaluate certain parts of the system within a controlled environment. The test was not designed to replicate the manner in which SVS will be used for an actual approach and landing sequence. The main difference was that the aircraft configuration steps were taken out of the process. That is, the standard reductions in speed, positioning of the flaps and approach decisions were not included as part of the test flights. For each approach sequence, the speed and flap settings were set at the beginning of each approach and not altered during the approach sequence. And since the aircraft never landed during the test flights, the final configuration was never reached and approach and landing decisions were never required. As such, the data collected during the study should be viewed as representing pilot-system interactions independent of the workload and decision environment of an actual approach and landing.

## **5.2 Part-Task Simulator Test**

In early May of 2002, NASA Ames will be executing a simulator-based SVS experiment for the purpose of providing data to the human performance modeling teams. (Note: This summary of the test is based on a test plan and it is expected that some of the details of the test will change.) The simulator emulates the instruments and controls of a generic air

transport. It consists of a large screen to present an out-the-window view, smaller screens to represent standard flight displays and the SVS display and a touch screen monitor and joy stick to emulate flight control inputs. Test subjects will assume the roll of pilot flying (PF) while members of the experimental team will function as pilot-not-flying (PNF) and air traffic control. Each of two test subjects will perform several approach and landing sequences in a variety of conditions with and without SVS including IMC and VMC, manual and coupled approaches, vectored approach, late runway reassignment, missed approach and a system failure resulting in terrain presentation mismatch. The PNF will support the test subjects in the distribution of tasks as would occur during an actual flight. The test subjects will be fitted with a helmet-mounted eye tracking system that will record visual attention location throughout the test. The data collected during each approach and landing will include:

- Time stamped video with audio and eye fixation overlay
- Textual data describing
  - Aircraft position and orientation
  - System settings
  - Control inputs
  - Any warnings or alerts generated by the simulated aircraft systems

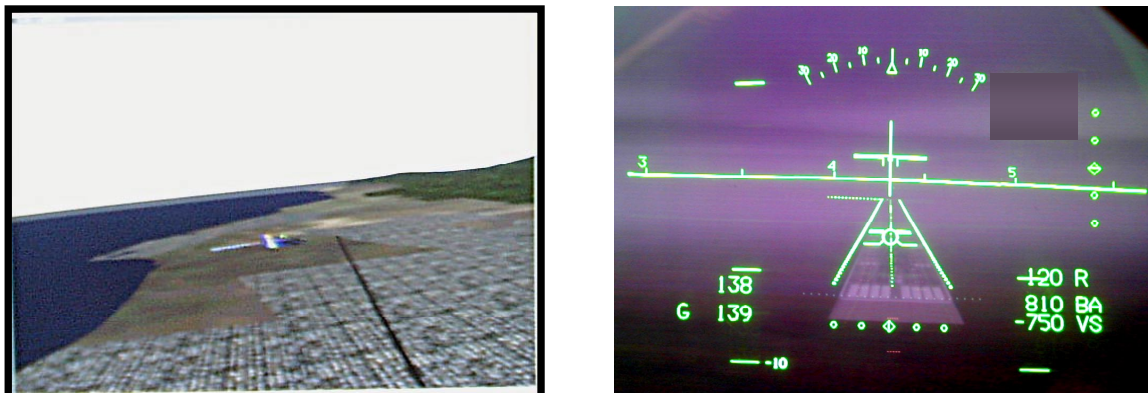
In addition, post-test questionnaires will be administered to assess subjective workload and SA differences across each trial. The data resulting from this experiment will be provided to the modeling teams as soon as it is available.

There are two issues related to the test that are of particular interest to the modeling teams and may affect how the resulting data is used. The first issue involves differences between the displays used in the simulator and those used in current commercial B757s. The primary flight display and navigation display used for the non-SVS baseline simulator runs differ somewhat from the ADI and HSI used in the B757. While the same information is displayed, the layouts differ. The simulator version of the primary flight display (Figure 5) is similar to the instrument overlay used by most of the SVS designs.



**Figure 5 - Simulated Primary Flight Display (left) and Navigation Display (right)**

Likewise, the SVS concept used for the simulation experiment differs from the concepts presented in this document. Specifically, the instrument overlay differs somewhat in information content and layout (Figure 6).



**Figure 6 - Simulated SVS terrain image (left) and flight instrument overlay (right)**

The second issue relates to the baseline instrumentation that can be emulated by the simulator versus what was presented in the baseline B757 document. The simulator can only emulate the RNAV approach instruments and procedures rather than the ILS instruments and process described in Leiden et al, 2002. There is some concern that differences in the cues provided by the two different system may confound modeling results if the simulator-based data is used with the ILS-based task sequence and SA information. As a result, NASA Ames has asked Micro Analysis & Design to update the baseline document with RNAV information. The updated document will be made available to the modeling teams by mid June 2002.

## **6 Using SVS**

The use of SVS is purely notional at this point since there are no FAA certifications or procedures. As such, it is difficult to determine if the use of the system will represent a whole new way to fly or simply be another supporting instrument. The concept of operations information provides ideas and goals for what the system will do and how it should be designed but does not discuss how pilots will actually use it down at the level of individual task steps. Likewise the simulations and test flights using SVS have focused on either specific research issues related to design or use of the system independent of other flight concerns. Given these limitations, we have not attempted to present a task decomposition for approach and landing using SVS. We do, however, start with a discussion of some tasks that probably won't change with SVS use. Following that, we discuss how SVS may change the cues that are available to pilots.

### **6.1 Task Sequence**

The procedures for aircraft stabilization during approach probably won't change much based on the use of SVS. The speed and flaps settings used to slow and stabilize the aircraft, the required callouts for communication between pilots, the use of checklists to verify the completion of required tasks and the communication with ATC will all still occur during the approach sequence.

One change that may occur relates to the timing of the configuration steps. In IMC stabilization steps are usually completed earlier in the approach than during VMC. The use of SVS may allow pilots to delay some configuration steps during IMC.

### **6.2 Pilot Interaction with SVS**

One of the most difficult issues throughout this data collection effort has been the characterization of the how SVS supports the pilots in IMC. During the pilot interview, the interaction was consistently represented by one basic concept. This concept is represented by the flight precept that 'one peek is worth a thousand scans of the instruments' and that the use of SVS gave a level of confidence and comfort to the subject pilot during approach. The idea is that no matter how much a pilot trusts the instruments, they are aware that interpreting what the instruments are indicating has the potential for error and that the independent check provided by a peek at the runway or other landmark provides that sense of confidence. The subject pilot used statements like, "increased comfort level", "reduced worry" and "increased confidence in the approach" to describe how it felt using SVS.

Given these statements it was tempting to characterize the use of SVS as the same as flying during daytime VMC. However, the subject pilot rejected this notion indicating that the cues provided by SVS create an interaction that falls somewhere between scans of ILS instruments and the out-the-window view during daytime VMC. With this understanding in mind, we have attempted to define the differences between the cues provided by SVS and what a pilot sees or does during daytime VMC. This section focuses on those differences as a way to characterize the interaction of the pilot with SVS. We have also found that the SVS cues are highly dependent on the implementation of the system and as

such have used variations in the NASA and Rockwell Collins concepts (as shown in Figure 2) to present this interaction characterization.

### **6.2.1 Closure and Crossing Rate Interpretation**

Pilots have learned to interpret the position and alignment of the aircraft as a function of the cues provided by the change in the view of the terrain outside the cockpit. Closure and crossing rates are interpreted by the perceived rate of change of the size of features ahead and around the aircraft. The terrain map feature of SVS provides closure and crossing rate cues similar to those available during daytime VMC. However, the level of the cues provided seems to decrease with the level of fidelity of the view of the terrain. The subject pilot indicated that while the generic texturing of the Rockwell Collins concept provided more of such cues than did ILS instrumentation, the detail provided by the photo texturing of the NASA concept was easier to interpret compared to the Rockwell Collins concept.

There are also two issues related to the field of view provided by SVS. The cockpit windows provide a much greater usable field of view than is provided by the SVS concepts. Being able to see terrain features to the side of the aircraft during daytime VMC increases the available cues used for crossing rate interpretation. The SVS concepts limit the pilot to the terrain cues that are ahead of the aircraft. The other issue relates to the view provided while turning the aircraft. During VMC, a pilot would be able to look out a side window or move his head forward to obtain terrain cues during a turn. Again, the SVS concepts do not present these types of cues.

### **6.2.2 Crosswind Situation**

In a crosswind, a pilot is forced to orient the nose of the aircraft to counteract the effect of the wind. The result is that the nose of the aircraft can be somewhat deviated from the actual direction of travel. In this situation, the pilot does not look in the direction the aircraft is pointing rather he/she looks in the direction of travel by turning their head. In this way the closure and crossing rate interpretation is still relevant to the position of the aircraft relative to the terrain and direction of travel. The SVS concepts limit the terrain view to the direction the aircraft is pointing. As such, the perception of aircraft location based on perceived closure and crossing rates can be disrupted in a crosswind situation.

### **6.2.3 Tunnel Navigation**

The tunnel navigation component of the SVS concepts provides navigation cues beyond what is available to pilots during daytime VMC. In one sense, the tunnel can be thought of as a combination of the glide slope and localizer as the bottom, top and sides of the tunnel help the pilot to keep the aircraft within a defined approach path. However, it goes beyond that with the capability to represent altitude stepped approaches where a pilot is called on to level off between descent steps or for circular approaches that require the pilot to be lined up with the runway at the end of an arcing and descending turn. The tunnel allows pilots to follow a visual representation of the approach rather than relying on their interpretation of instrument cues to maintain the approach profile.

Both SVS concepts use an aid to help the pilot maintain position within the tunnel. The NASA concept uses the ghost aircraft (sometimes referred to as the *follow me* aircraft) to



lead the pilot along the path. The task involves keeping the velocity vector aligned with the tail of the ghost. The Rockwell Collins concept uses a magenta colored box that borders the tunnel and leads the aircraft along it. The pilot is required to keep the velocity vector within the magenta box as it travels ahead of the aircraft. While the idea of traveling along the tunnel is highly intuitive and the idea of following something along it makes the task easier, there are some issues related to cue differences and performance between the magenta box and ghost aircraft implementations.

The magenta box of the Rockwell Collins concept represents the aircraft along the tunnel 5 seconds from the current time. If the velocity vector is within the box, the aircraft will match that velocity and direction in that position along the tunnel 5 seconds from the current time. The task of positioning the velocity vector on the ghost aircraft of the NASA concept requires the pilot to make constant minute changes as the size of the ghost is relatively small compared with the movements of the velocity vector. In contrast, the task of keeping the velocity vector within the magenta box requires a lower level of workload as the box presents a much greater area on the screen (creating the effect of larger maneuver tolerances) than the ghost aircraft. The subject pilot indicated that the difference in workload was not so much in the control manipulation as it was in the attention required to perform the tasks.

The different graphical implementations of the tunnel represent different levels of cue availability. The Rockwell Collins tunnel shows a continuous connected path that may make it easier to see the extended tunnel ahead of the aircraft allowing the pilot to anticipate changes in the flight path. The NASA implementation does not enclose the tunnel or connect the individual tunnel pieces. This may make it more difficult to see the tunnel as it extends ahead of the aircraft limiting the ability of the pilot to anticipate the flight path. However, there is a trade-off in terms of screen clutter. The Rockwell Collins tunnel implementation uses more graphics overlaid on the terrain image. This clutter could make it difficult to distinguish between the line for the artificial horizon and lines from the tunnel especially during turns.

Another issue relates to convention violations within the representations. The first concerns the predictive nature of the magenta box versus the standard use of the velocity vector. The velocity vector has traditionally represented the flight path of the aircraft based on control inputs at the current time. The task of positioning it within the magenta box representing a position 5 seconds away violates that convention. The second issue involves the implementation of the ghost aircraft. Pilots following an aircraft know that they need to turn inside a lead aircraft to be able to maintain relative position. While the ghost aircraft resembles such a lead aircraft it violates the convention in two ways. First, the ghost aircraft symbol indicates a turn by yawing rather than banking, which makes it difficult to notice when the turn begins. Second, the task of following the aircraft involves keeping the velocity vector on the ghost aircraft symbol rather than ahead of it during a turn as the military formation convention dictates (many commercial pilots have military backgrounds). It is difficult to determine what the effects of these convention violations will be, but it is anticipated that with training and increased use the differences in convention should become less salient.

One report (Stark, 2001) indicated that the use of tunnel navigation did not increase the pilots SA during the approach phase as was expected. They suggest that the ease of using the tunnel navigation to maintain the approach path may somehow be reducing the amount of information required for the task. It is also possible that the environment of the test, that limited the tasks and decisions required of the pilot, contributed to a lowered sense of or need for awareness.

#### **6.2.4 SVS as Aid to Visional Transition**

Instrument approach procedures are designed to aid the pilot during IMC and to help him get the aircraft below the cloud deck to a point where visual contact with the runway and continuing the approach to a landing are possible. The subject pilot indicated that when first breaking out below the clouds there is an adjustment period between using the ILS instruments and becoming oriented based on the visual inputs out the window. The difficulty making this adjustment may relate to identifying terrain features and correlating that to aircraft position. He indicated that using SVS might aid that transition as the pilot will already have an idea of the features and their orientation prior to breaking out below the clouds.

#### **6.2.5 Situational Awareness in IMC – no SVS vs. SVS**

This section focuses on the differences in cues available from SVS vs. the cues available in the standard B757 instrumentation for IMC. Since the most significant benefit of SVS touted by the subject pilot was the improved situational awareness (SA), it is important to compare the cues from SVS with standard B757 instrumentation to identify how it impacts SA. However, before this is done, it is worthwhile to present the Endsley (1999) decomposition of the three levels of SA.

- **Level 1 SA – Perception of the elements in the environment** - The first step in achieving SA involves perceiving the status, attributes, and dynamics of relevant elements in the environment. The pilot needs to accurately perceive information about his/her aircraft and its systems (airspeed, position, altitude, route, direction of flight, etc.), as well as weather, air traffic control (ATC) clearances, emergency information, and other pertinent elements.
- **Level 2 SA – Comprehension of the current situation** - Comprehension of the situation is based on a synthesis of disjointed Level 1 elements. Level 2 SA goes beyond simply being aware of the elements that are present to include an understanding of the significance of those elements in light of the pilot's goals. Based upon knowledge of Level 1 elements, particularly when put together to form patterns with the other elements, a holistic picture of the environment will be formed, including a comprehension of the significance of information and events. The pilot needs to put together disparate bits of data to determine the impact of a change in one system's status on another, or deviations in aircraft state from expected or allowable values. A novice pilot might be capable of achieving the same Level 1 SA as a more experienced one, but may fall short in the ability to



integrate various data elements, along with pertinent goals to comprehend the situation as well.

- **Level 3 SA – Projection of future status** - It is the ability to project the future actions of the elements in the environment, at least in the near term, that forms the third and highest level of situation awareness. This is achieved through knowledge of the status and dynamics of the elements and a comprehension of the situation (both Level 1 and Level 2 SA). For example, the pilot must not only comprehend that a weather cell—given its position, movement and intensity—is likely to create a hazardous situation within a certain period of time, but s/he must also determine what airspace will be available for route diversions, and ascertain where other potential conflicts may develop. This ability gives the pilot the knowledge (and time) necessary to decide on the most favorable course of action.

When comparing SVS to standard B757 instrumentation, the above descriptions of the three levels of SA highlights a very significant strength of SVS – SVS provides Level 2 and 3 SA directly to the pilot. For example, consider a missed approach at a terrain challenged airport. If the velocity vector is above the terrain profile on the synthetic display, the pilot knows that this means the projected state of the aircraft will clear the terrain (assuming, of course, that the aircraft performance is sufficient to maintain the climb rate implied by the velocity vector). Even if the missed approach is performed by the autopilot/autothrottle rather than manually, the pilot gains confidence in the automation and missed approach execution when he/she sees the velocity vector rise above the terrain.

In contrast, for a B757, the pilot would have to integrate Level 1 SA from different sources to have a similar level of confidence – the elevation of the terrain would come from the approach plates; aircraft heading comes from the navigation display; vertical speed comes from the vertical speed indicator and/or mode control panel; distance to the terrain could be approximated by mentally overlaying the terrain information on the navigation display or vice versa. Granted one of the primary reasons for requiring pilots to follow instrument approach/missed approach procedures is so that they do *not* have to integrate all this information to ensure terrain clearance. However, the point here is if the pilot doesn't follow the approach procedure or the aircraft is not where the pilot thinks it is (for whatever reason – distractions from cockpit alerts, ATC communication, etc.), ensuring terrain clearance becomes workload intensive, exacerbating an off-nominal situation. With SVS, terrain awareness is quickly acquired from a single display. Furthermore, the feedback provided by the velocity vector relative to the terrain image gives a prediction of what is needed (in terms of control inputs) for terrain clearance. In contrast, an awareness of terrain clearance is very difficult to achieve with standard instrumentation.

On a different note, SVS provides the pilot with the ability to crosscheck instruments that are fed from different data sources. The point of reference for the SVS display is the GPS position of the aircraft. On the other hand, runways equipped with ILS broadcast a localizer and glide slope that is independent of GPS. If the pilot is performing an ILS approach in IMC, the pilot can crosscheck the flight director (with inputs from ILS) on the PFD against the SVS. If the flight director is aligned with localizer and glide slope, then

the pilot should see that the SVS cue (either ghost aircraft, tunnel in the sky, or synthetic display of runway) is also in alignment. If both displays are in agreement, the pilot has added confidence in the information. Pilots routinely crosscheck their altimeters – SVS provides the ability to crosscheck other critical instrumentation as well.

## 7 Recommended Reading

1. [http://avsp.larc.nasa.gov/images\\_svs.html](http://avsp.larc.nasa.gov/images_svs.html)

This is NASA's Aviation Safety Program web site. It contains information related to the entire SVS project including history, concept descriptions and simulator and flight test documentation.

2. "Flight Test Evaluation of Tactical Synthetic Vision Display Concepts in a Terrain-Challenged Operating Environment" (Bailey et al, 2002).

This is the first report documenting the results of the Eagle/Vail flight test. It includes results relating to terrain awareness, workload, and SA.

3. "Preliminary Examinations of Situational Awareness and Pilot Performance in a Synthetic Vision Environment", (Stark et al, 2001).

This paper reports results of an early SVS simulator-based test.

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## 9 Acronyms

ADI	Attitude Display Indicator
AGL	Above Ground Level
ARIES	Airborne Research Integrated Experiments System
ATC	Air Traffic Control
AvSP	Aviation Safety Program
CFIT	Controlled Flight into Terrain
CDU	Control Display Unit
EGE	Eagle County Regional Airport
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FD	Flight Director
FMC	Flight Management Computer
FMS	Flight Management System
FO	First Officer
GSIA	Glide slope intercept altitude
GPS	Global Positioning System
HPM	Human Performance Modeling
HSI	Horizontal Situation Indicator
HUD	Heads Up Display
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
KIAS	Knots Indicated Air Speed
Kts	Knots
LNAV	Lateral Navigation
MCP	Mode Control Panel
ND	Navigation Display
OM	Outer Marker
PF	Pilot Flying
PFD	Primary Flight Display
PNF	Pilot Not Flying
RNAV	Area Navigation
SA	Situation Awareness
SME	Subject Matter Expert
STAR	Standard Terminal Arrival Route
SVS	Synthetic Vision System
TCAS	Traffic alert and Collision Avoidance System
VASI	Visual Approach Slope Indicator
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
VNAV	Vertical Navigation

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